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Quarterly Progress Report, Jun 1993 - Aug 1993
ONR Contract Number N00014-91-J-1577
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Our work on autonomous-agent planning continued on several tracks.

One track focused on the the development of concepts for runtime planning. Robot planning is concerned with the control of ongoing physical processes in real time. Therefore, planning and execution have to be tightly coupled. The robot controller has to activate the planning process on subtasks if risks, oportunities, or plan failures are detected or necessary information becomes available. It has to interrupt the planner if the world model used by the planner is detected to be outdated. The planner has to swap in its revisions for the plan while the robot controller executes the plan. These interactions require planning and execution to communicate and to synchronize their actions.

In our XFRM planner, planning is implemented as a process that runs in parallel with the execution process. In this research, we have been studying extending XFRM's robot control/plan language RPL with a statement RUNTIME-PLAN that activates the planning process with parameters such as the subtask the planner should revise or the time resources available.

The work in the area of runtime planning focused on:

- Description of other architectures for the integration of planning and execution in robot control. Exploration of possibilities of runtime planning to exploit oportunities, and to react to contingencies and risks detected by the execution process.
- Design of mechanisms for the synchronization and communication between the planning and the execution process.
- Rough design of the implementation of runtime planning.
- Exploration of different design alternatives for selective projection of subplans, and for swapping revisions into the plan while the plan is executed at the same time.

In addition, we spent some effort analyzing, optimizing, and proving correct our new time-map algorithm. We were able to provide a formal semantics for our probabilistic rules, and show that the program generates a given timeline with the probability specified by the formal semantics. Because the probabilistic rules specify Poisson-distributed events, this analysis requires defining probability distributions on continuous time as the limiting case of probability distributions on discrete time as the number of time instants per second approaches infinity.

This document has been approved for public release and sale; its distribution is unlimited.

In our work on robot sensing, we made great strides. The first major step forward was realization of a real-time visual tracking environment that can support tracking of multiple targets in multiple cameras on standard workstations. The system implements a variety of basic tracking methods, and supports definition of collections of tracked objects that move in some constrainted fashion.

That led to the second major step forward, the implementation of monocular and stereo visual servoing systems. The stereo system is currently being tested to see how fast it can be driven and accurate it is. Initial experiments indicate that speed is limited only by how fast we can reliably track objects as they move across the screen. Accuracy is limited by the accuracy of the edge-finder. Under reasonable working conditions (two cameras 30 centimeters about at a distance of 1.2 meters), we have repeatably achieved positioning accuracy on the order of plus or minus 1.5 mm.

We have also been working on a model of two-dimensional object recognition, which would be appropriate for recognizing stable wall features like pictures and light switches. The model is based on the idea of finding adjacent pairs of low-curvature boundary segments (which we call "U's") and using them to test for the presence of a model in a scene. Preliminary experiments show that U's are stable features that are easy to acquire, and that provide a fast but highly selective for the presence of an object whose boundary includes such features. We are testing this hypothesis by embedding the U-finder in an algorithm for verifying the presence or absence of a model in a cluttered scene.

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Activities:

Michael Beetz, talk on "Improving Robot Plans During their Execution," given at the Bavarian Center for Knowledge-based Systems/ University of Erlangen, Erlangen, Germany (August 16), the Technical University of Darmstadt, Germany (August 18), and the German Research Center for Artificial Intelligence, Saarbruecken, Germany (August 23)

Drew McDermott, panel discussion at AAAI on "Pros and Cons of Software Evaluation," July.

Drew McDermott, Nomad User's Group meeting, Naval Research Laboratory, July.

Publications:

Sami Atiya and Gregory D. Hager, in press, "Real-Time Vision-Based Robot Localization," *IEEE Trans. on Robotics and Automation.*

Gregory D. Hager, in press, "Solving Large Systems of Nonlinear Constraints with Application to Data Modeling," *Interval Computations*

The following have been revised and resubmitted to journals after refereeing:

Gregory D. Hager, "Task-Directed Computation of Qualitative Decisions from Sensor Data, Submitted to the *IEEE Trans. on Robotics and Automation.*

Personnel Support:

- *Graduate Students (full time):* Sean Engelson, Michael Beetz, Wenhong Zhu
- *Graduate Students (half time):* Amy Wang
- *Post-doc (half-time):* Hemant Tagare
- *Secretary (half-time):* Paula Murano

Expenditures:

The accompanying table shows the figures for expenditures to date, including amounts committed but not actually spent.

Overall Status and Plans:

The analysis and optmization of the time-map algorithm has taken longer than expected, and that's holding up our tests of the overall planner. We *hope* to get those underway soon.

The implementation of runtime planning is proceeding.

We are adapting the visual tracking algorithms to the case of a mobile robot homing on familiar landmarks.

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LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
NON-LADDER ACAD $ RES APPTS	0	6,504.18	9,511.60	16,015.78	-16,015.78
FACULTY SUMMER COMP	51,599	36,577.78	50,377.56	86,955.34	-35,356.34
MANAGERIAL & PROFESSIONAL	0 6,672.10	1,827.11	8,499.21	-8,499.21	
CLERICAL & TECHNICAL	25,719		35,874.30	35,874.30	-10,155.30
STUDENT ASST.	135,450	23,846.12	60,631.09	84,477.21	50,972.79
DIRECT WAGES	0		344.00	344.00	-344.00
OTHER YALE STUDENTS	0		15,632.00	15,632.00	-15,632.00
EMP. BENEFITS	29,014	9,930.48	36,561.03	46,491.51	-17,477.51
D/P SUPPLIES	0	418.14	2,978.78	3,396.92	-3,396.92
MINOR EQUIPMENT & FURNISHINGS	0		379.00	379.00	-379.00
MISC MATERIALS	0		55.17	55.17	-55.17
D/P SVS.	38,579	7,000.00	28,951.00	35,951.00	2,628.00
D/P SOFTWARE	6,000		2,633.00	2,633.00	3,367.00
FREIGHT & TRANSPORTATION	0		821.47	821.47 -821.47	
PHOTOCOPYING	6,430	294.43	4,152.26	4,446.69	1,983.31

LEDGER DESCRIPTION	AMOUNT BUDGETED	COMMITTED (NOT PAID)	PAID TO DATE	TOTAL EXPENSES	REMAINING BALANCE
PRINTING	0		313.80	313.80	-313.80
MISC SERVICES		270		270	-270
COMMISSIONS	0		25.00	25.00	-25.00
OTHER PROFESSIONAL	0		152.32	152.32	-152.32
DP EQUIP MAINTE-NANCE	0		581.16	581.16	-581.16
TRAVEL (DOMESTIC)	12,860	807.00	15,712.39	16,519.39	-3,659.39
TRAVEL (FOREIGN)	0		2,913.98	2,913.98 -2,913.98	
OFFICE SUPPLIES	3,215	45.48	1,039.57	1,085.05	2,129.95
PERIODICALS	0		1,703.89	1,703.89	-1,703.89
POSTAGE	0		1,291.98	1,291.98	-1,291.98
DUES & MEMBERSHIP	0		160.00	160.00 -160.00	
TUITION REMISSION	69,162	19,228.00	21,436.00	40,664.00	28,498.00
HEALTH INS.	0	1,400.00	1,191.00	2,591.00	-2,591.00
TELEPHONE	3,215	232.65	599.66	832.31	2,382.69
DATA PROC. EQUIPMENT	189,000	23,733.60	84,846.02	108,579.62	80,420.38
INDIRECT (OVERHEAD 64.0%)	212,215	48,281.28	197,364.31	245,645.59	-33,430.59
TOTAL:	782,458	166,682.35	598,619.34	765,301.69	17,156.31
		OVERHEAD ANTICIPATED:			6,695.15

SPENDING BALANCE AVAILABLE AS OF SEPTEMBER 9, 1993: 10,461.16